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Application of Laser Doppler technique in detecting the dynamic parameter of MEMS device

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Abstract: In order to test the dynamic performance of MEMS devices accurately, the laser Doppler vibrometer was adopted to test the frequency characteristics and surface vibration of the MEMS scanning mirror. The measuring formulas of the object motion velocity and displacement were derived. A kind of MEMS scanning mirror was tested using the established optical testing system. The measurement results show that the resonance frequency characteristic and the transient response characteristic is 269Hz and 60ms respectively which are consistent with the theoretical analysis. The method has significant reference value to the application of the laser Doppler technique.

Introduction

With the development of MEMS technology, it is more urgent to achieve the rapid detection of dynamic characteristics of MEMS devices [1]. Since the MEMS device has the advantages of small volume, high speed, small deformation and susceptible to outside interference factors, the traditional detection methods can not meet the demand of real-time measurement for its characteristics. Laser Doppler detection methods is an optical detection method, and has the advantages of non contact measurement, high resolution and fast response which is a qualified way in MEMS device dynamic performance test.

As an optical element, MEMS scanning mirror has important applications in laser imaging[5], bar code recognition[6], data storage[7]and medical imaging[8]. Because the performance of the MEMS scanning mirror depend on its frequency characteristics and mirror vibration, it has the important value to research that how to achieve real-time and accurate measure. In this paper, MEMS scanning mirror frequency characteristics and surface vibration measurement were realized by using laser Doppler technique.

Laser Doppler measurement principle

The principle of laser Doppler technology was depicted schematically in fig.1.

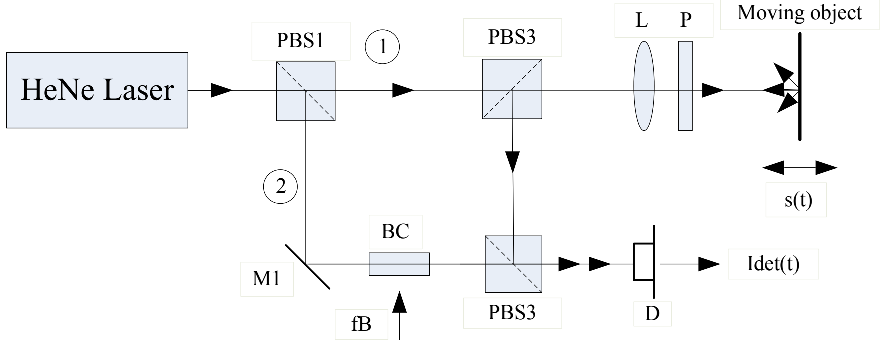


Fig.1 Optical system of laser Doppler vibrometer schematic diagram

Laser beam emitted by HeNe lasers is split into two beams after splitter PBS1, the measuring beam 1 and the reference beam 2 respectively[6] [7]. The measuring beam is incident to a moving object through the beam splitter PBS3, lens L and 1/4 wave plate lens P. While the reference beam 2 is received by photoelectric detector through a plane mirror M1, Prague unit BC and beam splitter PBS2 . Here the Prague BC is an acousto-optical device, can make the reference beam frequency offset 40MHz. In addition, the measuring beam1 which reflected back from the moving object through P, L, and PBS3 also enters the photoelectric detector D, and generate interference with the modulated reference beam 2. Phase difference is calculated through the optical path difference of two beams , thus achieving frequency change value.

The displacement of a moving object changes $s(t)$ will cause phase changes of the measuring beam which reflected back, thereby producing a phase modulation $\varphi(t)$, the relationship between them is shown as formula (1):

$$\varphi(t) = 4\pi s(t)/\lambda \tag{1}$$

In which, the laser beam wavelength is expressed as λ . According to the following relationship:

$$\begin{cases} ds/dt = v \\ d\varphi/dt = 2\pi f \end{cases} \tag{2}$$

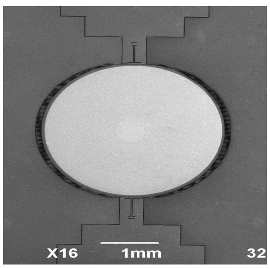
The corresponding frequency change $\Delta f(t)$ can be derived from the formula (1):

$$\Delta f(t) = 2v(t)/\lambda \tag{3}$$

The above parameter $\Delta f(t)$ is known as the Doppler frequency shift. Therefore, according to the Doppler frequency or phase change, we can deduce the velocity and displacement of the moving object which follow the measuring beam1 direction respectively.

Laser Doppler test device

According to the different driving methods, MEMS scanning mirror can be divided into the piezoelectric drive mode, electromagnetic drive mode, magnetostrictive drive mode, thermal driving mode and electrostatic drive and so on. Compared with the other four driving modes, the electrostatic drive MEMS scan mirror produced by the laboratory has the following advantages: small volume, low power consumption, low driving voltage and large scanning angle. The SEM photograph and the devices photo after packaging are shown in figure 2 and figure 3 respectively.



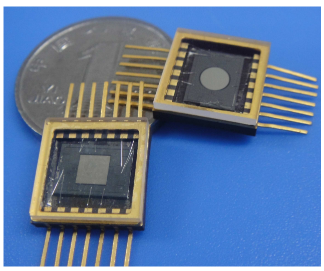


Fig. 2 SEM images for the fabricated micro scanning mirror.
Fig. 3 Photos of the fabricated micro scanning mirror.

In this paper we use the laser Doppler vibrometer(MSA-500-M, Polytec company, German) to perform the test to get the frequency characteristic and vibration mode of the mirror. The apparatus can distinguish the minimum rate for 0.02 μm·s-1·$\sqrt{Hz}$ -1 , and the bandwidth of operation can achieve a maximum of 1MHz. The diameter spot of laser beam is 1um due to adopt the objective lens with 10 times. Figure 4 is the experimental apparatus of measuring the dynamic properties for the MEMS scanning mirror. Here the laser Doppler vibrometer will provide a signal to drive the MEMS scanning mirror with voltage of 1V, square wave, sweep range of 0~10KHz, and this signal will turn to 15V to obtain the frequency characteristics and mirror vibration characteristics through a voltage amplifier[8]. The whole testing process were carry out at 10000 purification room with the normal temperature and pressure environment.

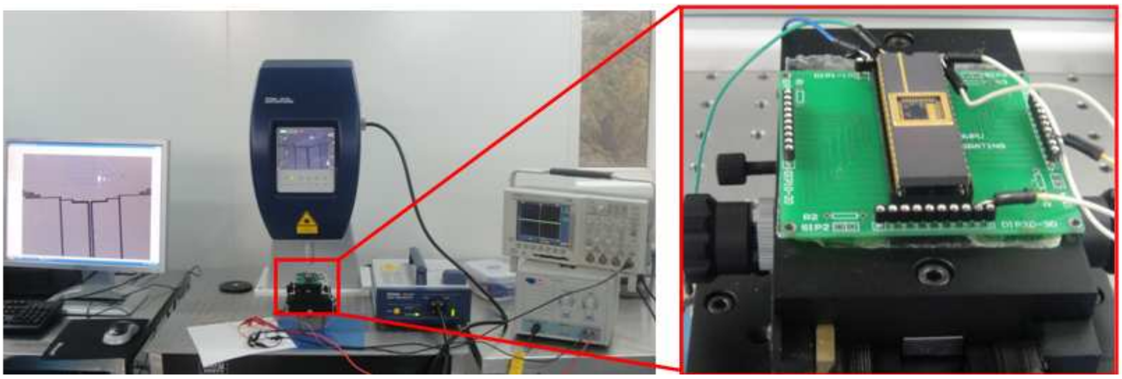


Fig. 4 Test equipment for the fabricated micro scanning mirror.

Measurement results and analysis

1 Frequency resonance and transient resonance

In the scanning mirror vibration conditions, the frequency sweep is tested. the laser Doppler vibrometer is used to measure the resonant frequency of the MEMS scanning mirror, and the measuring results are shown in figure 5. MEMS scanning mirror obtain maximum amplitude in 269Hz, and the maximum mirror torsion angle is obtained at the same time. The corresponding drive signal frequency is 547Hz, the ratio about 1:2 is very good agreement with the characterization of the parametrically excited system. In addition, the vibration of the micro scanning mirror would express the damped oscillation until stabilization under the response frequency.From the graph 5 can also be found that MEMS scanning mirror has obvious vibration in the range of 230Hz~310Hz, but the vibration amplitude is smaller than the peak value.

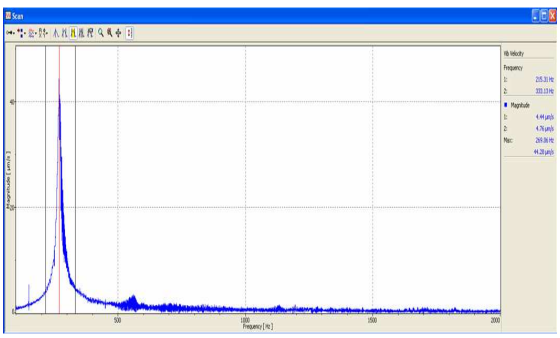


Fig.5 Resonant frequency test of MEMS scanning mirror

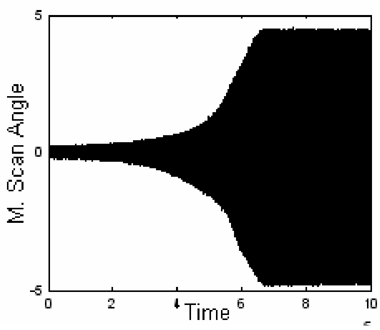


Fig.6 Transient response of MEMS scanning mirror

Figure 6 shows the experimental data for the behavior of the output amplitude until the system reaches steady state, and the square-root sinusoid is employed as the waveform of the excitation. The oscillatory behavior in the transient response diminishes at the first period of working time when the excitation frequency is very close to 547Hz,and transient response is about 60ms.

2 Scanning mirror vibration modal

The vibration modal of the MEMS scanning mirror is measured using the laser Doppler vibrometer. Static horizontal mirror is set as the datum plane, a rectangular region with 3 rows and 9 columns of 27 point is selected as test area to research the Z direction vibration of the mirror. From the Figure 6 we can see when MEMS scanning mirror in the resonant state, the 27 basic points are maintained in a plane, it indicates that portion of the mirror does not appear obvious deformation, ensuring the imaging quality of MEMS scanning mirror.

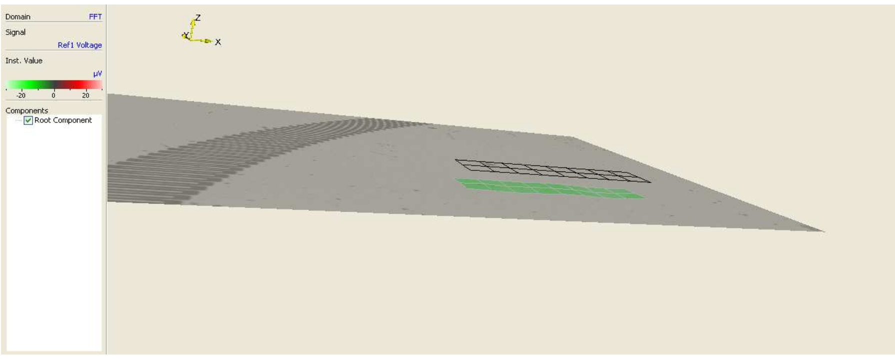


Fig.7 MEMS scanning mirror vibration test

Conclusion

The laser Doppler technology is used to realize the MEMS device vibration detection. Base on the established experiment testing system the frequency characteristic of a MEMS scanning mirror which is produced by our laboratory was tested. The experimental results show the test results are consistent with theoretical calculation results. The method can quickly obtain the resonant frequency and surface vibration model, improving the work efficiency of the device research and development.

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